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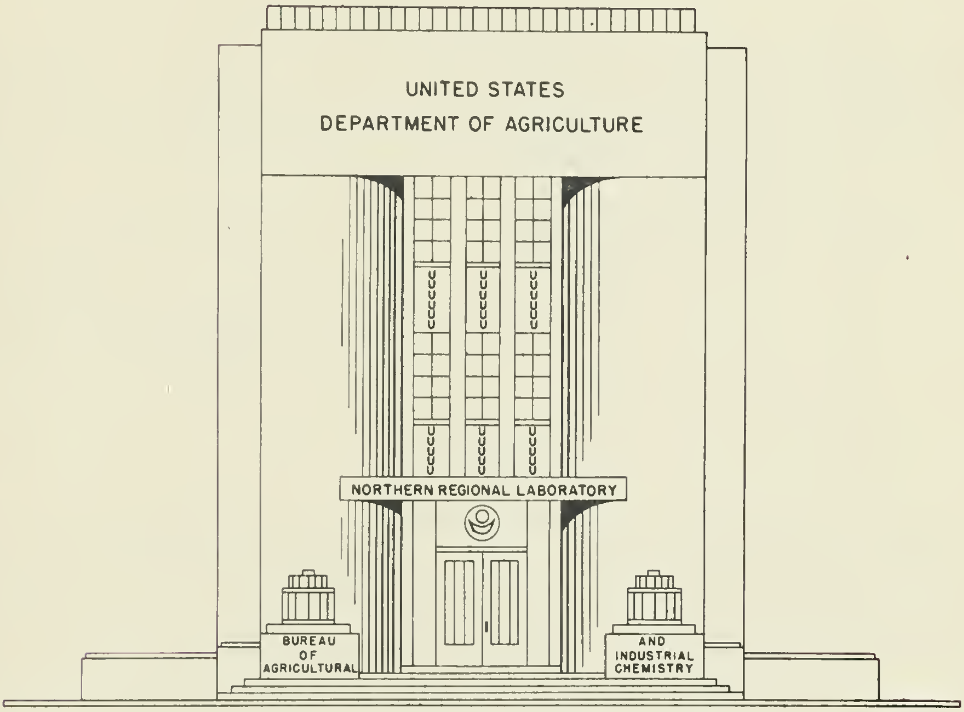
GRAIN STRUCTURE AND GRAIN STORAGE



By
M. M. MacMasters

NORTHERN REGIONAL RESEARCH LABORATORY
PEORIA, ILLINOIS

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By

M. M. MacMasters[1]

Northern Regional Research Laboratory[2]
Peoria, Illinois

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INTRODUCTION

An understanding of the nature of cereal grains and their behavior during storage is a necessary basis for their proper handling on the farm or after they have left the farm. The 5 to 30 percent damage that occurs annually in stored grains not only results in a huge waste of food and feed but is a financial hazard to grain growers, elevator operators, and grain processors. Dockage for damage brings to growers and dealers considerably lower prices for their grain. Damage to grain is eventually reflected in the lowered yields and quality of products made from it, as well as in difficulties encountered in processing.

Growers, dealers, and processors are confronted with the necessity for protecting grain from rodents, insects, and microorganisms, especially molds. Since the part played by rodents and insects in the spoilage of grain is quite widely understood, the present discussion will be largely confined to the action of microorganisms in causing spoilage. Grain stored at high moisture content is especially susceptible to damage by microorganisms. The chemical changes and heating which result have burdened farmers and grain dealers with the responsibility not only of properly storing sound grain to maintain its quality, but also of handling unsound grain in such a way as to keep it from getting worse.

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[1] Chemist, In Charge, Starch Granule Section, Starch and Dextrose Division

[2] One of the laboratories of the Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration, U. S. Department of Agriculture

Certain phases of research at the Northern Regional Research Laboratory have been concerned with determining the suitability of stored and artificially-dried grain for industrial processing. Some of the work was done in cooperation with the Illinois Agricultural Experiment Station and was especially concerned with the effect of grain maturity and of conditions of artificial drying on the value of corn for wet milling for starch production. In connection with these studies, an extensive survey was made of what has been published on the subject, to determine what is known about causes of grain spoilage in storage--especially causes other than insect and rodent infestation. Results of the survey form the basis for this publication.

Much of the text material presented here is based on a review given by the author in a series of 1-day schools for country grain dealers, held during February 1952 in four grain-producing areas of Illinois. The schools were held by the Illinois Grain and Feed Institute, sponsored by the Business Education Service of the Illinois Board for Vocational Education with the cooperation of the University of Illinois Extension Service. The review was issued as a news release which appeared in *American Miller and Processor*, *Grain and Feed Journals*, *Northwestern Miller*, and *Feedstuffs*. The interest shown at the schools and the requests later received by the Northern Regional Research Laboratory for reprints of the published news release have indicated the value of preparing the review in a form suitable for wider distribution.

THE GRAIN HANDLERS' PROBLEM

Farmers, dealers, and processors who must handle grain are confronted with a serious problem. They have to deal with a material which varies from lot to lot. Consequently, it is impossible to treat all lots of grain alike.

Natural factors cause much variability in grain. Chief among these are weather conditions, differing from year to year, which affect the state of maturity and the moisture content of the grain at the time of harvest. Variability also results from attack of the grain in the field by insects and microorganisms.

Relatively recent changes in agronomic practices have in many cases contributed to the grain handlers' problem. In the case of corn, for example, a tendency to plant long-season hybrids has led to the harvest of much grain at high moisture content, in years when climatic conditions have favored early harvest. Trends toward mechanized harvesting also are important. The harvesting of corn starts at least as early and is much more quickly finished when done by mechanical pickers than it used to be when the husking was done by hand. As a result, more corn is at high moisture content when harvested. The picker-sheller, which is currently coming into favor, harvests corn at about 20 to 30 percent moisture content. Similarly, the combining of wheat often results in the harvesting of grain with moisture content higher than is safe for storage.

Because of these and similar changes in practice, the artificial drying of grain has become more and more common during recent years. How the drying procedure is carried out determines whether or not the grain is damaged during artificial drying.

The grain handler may have to deal at the same time with sound, naturally dried grain, with sound or unsound high-moisture grain, and with artificially dried grain which may or may not have deteriorated in quality before or during drying. He must, therefore, be well aware of the exact condition of each lot of grain in his care, and must exercise constant vigilance in the individual treatment of each lot during storage. Sound grain must be so handled that it will remain sound. Grain of any degree of unsoundness must be kept from becoming of lower quality than it already is.

There is a considerable amount of information, published in various places, which can help the grain handler. Knowledge of the structure of the kernel aids in understanding the movement of moisture within the grain kernel as well as to and from it. The entrance of molds and other microorganisms into the grain and their growth there--a major cause of heating in storage--may also be understood from a knowledge of kernel structure. Certain characteristics are known which indicate various stages of grain spoilage. They often point to the cause of the damage and usually suggest appropriate means for preventing further decrease in quality. Information is also available as to how spoilage of different degrees and types may effect the value of the grain for a variety of end uses. The grain handler can profitably build with experience on the foundation of existing knowledge. In this way, he can become thoroughly intimate with the nature of his variable material, and with the method by which he can best handle each lot to conserve it for use.

STRUCTURE OF THE CEREAL GRAIN KERNEL

The cereal grain kernel consists of the true seed plus outer protective layers which are called the pericarp. The pericarp is, roughly speaking, the bran; however, in some milling operations not all of the pericarp is removed, while in others, the bran contains some endosperm, (aleurone and even sometimes horny endosperm) attached to the pericarp

The germ and endosperm are parts of the seed itself. The germ is composed of two parts, the embryonic plant and the scutellum which acts as a nourishing organ during germination. All oil which is separated industrially is contained in the germ. The endosperm is the storehouse for food for the germ during germination, and it is in the endosperm that most of the starch and gluten are found.

Certain structural details within the kernel are of especial interest to those concerned with storage. For example, at the upper edge of the corn kernel, above the germ, one often sees a slight peak. This is where the pollen entered through the silk at the time of pollination. It is believed by some authorities that mold spores also may enter through the pollen tube, before the grain starts to develop. That might account for the mold which is commonly found in the pericarp of grains.

Another possible place for mold to enter is through the relatively loose and open type of tissue that is found just under the tip cap in corn and at the base of cereal grain kernels in general. This tissue also permits rapid entrance of moisture during tempering and steeping when the grain is milled and probably is the exit space

for water during drying. Most of the corn kernel is covered with a thick layer of relatively waterproof material which helps to protect the seed as it lies dormant. The loose tissue at the base of the kernel is continuous with similar tissue which extends all around the kernel, forming the cross-cell layer of the pericarp, so it would not be hard for molds to enter and grow in this entire area, and, indeed, this is where they are often found

Under the pericarp is a thin skin like layer which is the seed coat of the cereal grain. At the base of the corn kernel the seed coat and some other tissues combine to form a dark, somewhat thickened structure known as the hilar layer. The latter is the black area that is readily seen when the tip cap is pulled off. The film-like seed coat and the hilar layer form an inner protective coating about the seed, offering further resistance to the entrance of microorganisms and to the movement of moisture.

Another factor contributing to the problem of drying cereal grains is the dense nature of the endosperm, where each cell is packed with starch granules which lie embedded in a matrix of material which is largely protein. In corn, the very size of the kernel presents a drying problem since the outer portion may be too dry while the inner part is still very moist. Such a condition is analogous to "case-hardening."

STRUCTURE OF THE SOYBEAN

Grain dealers often have to store soybeans as well as cereal grains. Beans differ in structure from the cereal kernels. Soybeans are true seeds. The outer hull or skin is the seed coat, and the pod corresponds to the pericarp of the cereal kernel.

As in the case of the cereal grains, it is thought that mold spores may enter soybeans with the pollen. And at the place where the bean was attached to the pod there is a dark spot, the hilum where there is an opening into loose tissue, just as at the base of the cereal kernel, where molds may enter and through which moisture may move.

The bean has the two first leaves of the embryo greatly developed as storage tissue. They are known as cotyledons and are filled with oil, protein, and sugars for the nourishment of the embryo during germination. The cotyledons are large and dense and the movement of moisture through them is slow Hence the nature of the bean itself contributes to the problem of drying.

CAUSES OF SPOILAGE OF GRAINS IN STORAGE

How grain has been handled before storage is a most important factor. If it has been allowed to deteriorate in quality because stored at high moisture content for example, or if it has been mishandled as by allowing it to be wet by rain, its prime condition can never be restored. The best that the dealer can then do is to minimize further damage

Wet grain is a fine medium for the growth of molds, bacteria, or other microorganisms. Molds are most important causes of spoilage. The moisture content of stored grain is important not so much in itself but because it controls the relative humidity of the surrounding air. This is especially true at low atmospheric moisture levels. At the moisture levels at which grain is usually stored, the relative humidity of the air about it is extremely important. Mold growth occurs abundantly when the relative humidity is above 74 or 75 percent, and some kinds of mold will grow well when the relative humidity is as low as 65 percent. At lower relative humidities, molds may take months or even years to develop, but as soon as the relative humidity rises to about 74 percent or above, they develop rapidly from the spores already present.

The growth of microorganisms increases rapidly with increasing temperature, until the heat in the grain mass becomes so great that the organisms are killed by it. Storage at low temperature is always desirable for keeping mold growth as slow as possible. All practical means should be used to keep the storage temperature of grain low.

Since some molds can grow more rapidly than others at lower relative humidities, the kind of molds that are present influence the keeping quality of stored grain. It is best to assume that the most troublesome molds are present, that is, those that can grow well at low relative humidity (65 percent), and to act accordingly.

The "blue eye" of corn and wheat is caused by certain molds--Penicillia. To avoid damage by blue eye, it is important to control storage conditions so that these molds cannot develop and attack the germ of the grain.

"Sick wheat" is another type of spoilage which sometimes results from the action of molds. In other cases, molds appear not to be responsible. Bacteria may play a part in causing sick wheat, and even suffocation of the grain itself may lead to this type of damage.

The extent to which the oil within the kernel has broken down and formed free fatty acids is important in determining the safety with which grain can be stored. The more free fatty acid present, the more likely the grain is to spoil. High content of free fatty acids indicates probably that the grain has already started to spoil, even though it does not look bad. As molds visibly attack the grain, the free fatty acid content continues to increase.

A sound kernel is a living organism. Like other living organisms, it breaths or respires. Respiration of the grain produces some heat, just as our own breathing produces heat. If the grain is not stored so that this heat of respiration can escape, it may contribute to the overall heating of the stored grain, although, apparently, it is never the major cause of heating.

A more serious source of heating, however, may be the presence of other living organisms in the stored grain. Molds have already been mentioned, and the effect of their respiratory heat is very marked. Insects may be an added cause of heating. Even a few insects, localized within a pocket in the grain, can heat that area considerably.

The heat which they produce makes it more confortable for them and attracts other insects to join them and enjoy the moderated temperature. When the respiration of the growing insect colony increases the temperature so much that the insects become uncomfortable, they move out to the edges, forming an ever-increasing spherical zone of heating. Not only heat, but also moisture is produced by respiration. Hence the heat and moisture necessary to encourage rapid growth of molds may be centered in one zone within the grain. The molds then continue to increase the heating by their own respiration, and finally this originally small zone may become the focal point for heating of the entire bulk of the grain.

VISIBLE EFFECTS OF SPOILAGE

The first evidence of spoilage often is visible mold growth. In some cases, the first evidence of spoilage may be sourness which results from bacterial fermentation, but mold growth is more common.

The next step is noticeable heating. Molds can heat grain to a temperature of at least 122° to 132° F. Temperatures as high as 142° F. have been reported to be caused by mold growth. Bacteria can grow at temperatures that are too high for molds, and bacteria have been reported to heat stored grain to a temperature as high as 155° to 159° F.

If heating is permitted to continue, the grain will darken and become "mahogany" colored.

During the time grain is heating, changes take place within the kernel, so that when it is cut open it looks quite unlike a kernel of sound grain. In corn, for example, the endosperm first becomes less compact looking and appears more granular, later all evidence of the horny endosperm disappears and the entire endosperm looks very granular. Meanwhile, the germ has died, darkened, and partially decomposed. Often mold can be seen within the germ and endosperm, as well as in the hull. If the endosperm is examined under a microscope, it can be seen that the proteinaceous material which surrounds the starch granules has partly broken down, and the starch granules may be pitted. If the heating grain has reached a very high temperature, the starch may be light tan in color and behave more like dextrin than like starch. One way of making dextrin is by heating starch, and presumably this type of change has occurred naturally when the starch has been heated to a high temperature while still in the kernel.

METHODS USED AND SUGGESTED FOR CONTROLLING SPOILAGE

Perhaps the simplest step taken to control the spoilage of grain in storage is turning the grain to hasten its drying by air. This may give good results if the grain, at the start, is not very much above the safe moisture level and if the relative humidity of the air is in the "safe" area, below 74 percent. The same is true of drying with a forced draft of unheated air.

Treatment of moist grain with chemicals to inhibit spoilage has been widely suggested and investigated on a small scale. The chemicals generally used are those which inhibit the growth of molds or kill them. The result may be very good over short storage periods.

Carbon dioxide gas is sometimes used to slow down the respiration of the seed, molds, and bacteria and so inhibit heating. However, although it inhibits the growth of microorganisms, it may also suffocate the grain and kill it, thus making the kernel more liable to subsequent spoilage.

There is another fact which must be remembered when an attempt is made to store grain at a high moisture content. That is that even if the grain does not spoil under the conditions of storage, it still may not be acceptable to a potential buyer, just because of its high moisture content. Thus, dry millers of corn must have the grain at proper moisture or the right size grits will not be obtained upon milling. Wet corn millers, who produce starch, have sometimes used grain of high moisture content, but this at times has necessitated modifications in processing conditions. In some cases, for unknown reasons, considerable difficulty has been encountered in processing such corn. Similarly, wheat of high moisture content cannot be properly milled to flour. It is obvious that if grain is to be used for these or similar purposes, there is no advantage in holding it at high moisture content while using chemicals to prevent spoilage.

Another type of chemical treatment which may at times be advantageous is the addition of chemical drying agents to the grain. Sometimes the drying chemical is added in pellet form then the pellets generally have to be screened out before the grain is used. It has also been suggested that wooden blocks impregnated with the drying agent may be scattered through the grain and easily removed when their work is done. When chemical drying agents are used in any form, good mixing of them with the grain is very important, otherwise, wet pockets will be left where heating can start and spread to the bulk of the grain.

The best treatment for storing grain without danger of spoilage appears to be to keep the grain at such a moisture content that the relative humidity of the surrounding air will be less than 74 percent. Often this means that the grain must be artificially dried, a practice generally accomplished by use of heated air, although in dry climates unheated air is often used.

ARTIFICIAL DRYING WITH HEATED AIR

Grain can be badly damaged by improper drying. Overheating during drying is especially dangerous. Temperature alone cannot be used as the criterion for "safe" heating. Temperature, relative humidity of the drying air, rate of air flow, moisture content of the grain, and duration of the drying treatment are closely interrelated. For example, the higher the initial moisture content of the grain and the longer the drying time, the greater is the danger of damage from a high drying temperature. It is necessary to recognize, too, that it is the temperature of the grain itself, rather than that of the drying air, which is of first importance. Keeping this fact in mind, certain general rules for "safe" temperatures for drying can be drawn from published information.

If corn is to be used for feeding, drying temperatures in the range of 95° to 135° F. are recommended. Higher temperatures are said to decrease the feeding value of the protein. The difference in feeding value is probably no greater than a few percentage points and may, in some cases, be offset by the practical expediency of drying at a higher temperature. Changes in the protein brought about by high temperature probably account for the decreased feeding value which has been reported.

A temperature of 110° F. is often considered the maximum for safe drying of seed corn. If the initial moisture content of the grain is below 25 percent, however, some investigators consider 120° F. to be a safe drying temperature.

There is no definite information available as to what temperature is safe for drying corn which is to be used for dry milling. It is known, however that the dry corn milling industry much prefers to use corn that has dried naturally rather than grain that has been artificially dried.

For complete suitability it is generally conceded that corn which is to be used for starch production by the wet-milling process should not be dried at temperatures above 120° - 130° F. At higher drying temperatures the protein apparently is denatured and it is difficult for the miller to separate the starch from the protein. As a result, many complications arise during the milling process.

The recommended temperature for drying corn for use in fermentation for alcohol production is much the same as that for drying seed corn. If the corn has been dried at too high a temperature, the alcohol yield is definitely decreased but drying up to perhaps as high as 170° F. may not seriously affect the yield.

The safe maximum temperature allowed for drying wheat is somewhat higher than that recommended for drying corn. In Canada, the maximum temperature allowable for drying wheat is 180° F., while in England it is recommended that the temperature be not over 150° F. A difference in the average relative humidity of the atmosphere in the two countries probably accounts for the difference in allowed maximum drying temperature. If wheat is dried at higher temperatures, the baking quality of the flour is decreased. The wheat miller processes the wheat primarily for the baker, so it is of utmost importance to the miller that baking quality be not affected by treatment of the grain before or during storage.

It is generally advised that oilseeds such as soybeans, be dried at temperatures below 115° F. At higher temperatures the oil is decreased in value and the seed suffers changes which make removal of the oil more difficult.

Thus far, we have considered the problem of spoilage of grain during storage from the standpoint of the grain dealer. Sometimes the dealer cannot see why buyers do not want grain which looks and smells all right. From the point of view of the buyer, there may be a good reason. For better understanding, let us consider the matter from the standpoint of the millers who use corn, for example.

THE DRY CORN MILLERS PROBLEMS

In dry milling, corn is cracked between rollers. The aim is to break the kernel in such a manner that the germ and hull are readily separable from the endosperm, and the endosperm is cracked into as large pieces as possible most preferably into only two pieces.

The kernel is usually tempered for a short time before milling, so that the hull contains more moisture than the endosperm and the separation of the two is relatively clean. If the initial moisture content of the kernel is too high this result cannot be obtained; and the endosperm tends to be doughy at high moisture levels so that it does not crack sharply into clean pieces.

When corn has been dried too fast, the outer part of the kernel develops minute cracks and on milling the endosperm breaks into many small pieces A higher percentage of small grits is not desired by the industry.

Any treatment which causes death and breakdown of the germ renders corn difficult to degerminate, and also makes it hard to recover oil from the germ which is separated. In addition, oil from dead germ is of less value, because it contains a higher percentage of free fatty acids than is present in high grade corn oil

Consideration of these factors should make it clear to the grain dealer why the dry corn miller normally prefers to buy sound grain which has dried naturally

THE WET CORN MILLERS PROBLEMS

For wet milling, the corn is first steeped or soaked in a dilute solution of sulfurous acid. The wet corn is then coarsely ground and the hull and germ removed before the remaining endosperm is finely ground After removal of the fiber from the suspension of finely ground endosperm, the mixture of starch and corn gluten, known as mill starch, is allowed to flow down a long inclined flat bottomed trough known as a starch table. The starch is more dense than the gluten and settles out upon the table, while the suspended lighter gluten flows over the lower end of the table. The starch is further purified by centrifuging the remaining gluten away from it much as cream is separated from skim milk. In most starch factories a closed system is used, that is, no water goes to the sewer, but gluten is removed from the various process waters in which it is suspended and the water is reused

Moist corn is often hard to process for starch production, seemingly because of the nature of the corn gluten. Separation of the starch and gluten from such corn is often poor.

Wet millers often find kiln dried corn very difficult to process because it has been heated to too high a temperature It is almost impossible to separate protein and starch from overheated corn as relatively clean fractions Removal of the protein from the process waters is often almost impossible and the system becomes overburdened

with protein. The poor removal of starch from gluten leads to loss of starch into the feed, and the excess load to the feed house slows down production in the entire plant. The dead germ is difficult to remove whole, and recovery of oil is also difficult. The oil is of poor grade, being high in free fatty acid content. It is troubles such as these encountered in the processing of overheated corn that make wet milling companies reluctant to purchase corn that is known to have been kiln-dried.

TESTS FOR PROCESSABILITY

It is easy to detect grain which is too moist for proper processing. Often the appearance alone is enough, and if not, adequate means are available for determining moisture content of the grain. A more difficult problem is for the buyer to determine when dry grain has been damaged during drying or storage. If it has been sufficiently overheated to blister or discolor, inspection is sufficient. The same is true if visible mold growth is present. However, the grain may be damaged and yet look sound. In such cases, the damage can be estimated by determining the free fatty acid content of the oil. The method of approximate determination has been well established. The only drawback is that the sample must be taken to the chemical laboratory and the buyer must then wait about an hour for the chemist's report. The higher the free fatty acid of the grain, the less suitable the grain is for processing.

Another test has been suggested for detecting grain damaged by artificial heating or in storage. This is known as the T.T.C. test and depends on the determination of viability of the grain by use of 2,3,5-triphenyltetrazolium chloride, called T.T.C. for short. The compound is soluble and colorless. When it comes into contact with living tissue, such as that of a viable germ, it is changed to a red, insoluble compound. Thus, by cutting the kernel to expose the germ and then treating it with T.T.C., the germs which are viable are colored red while those which are not are colored only in some parts or not at all. The test is simple and can be run at trackside or elevator in about an hour. Anyone can learn to make the test in a week at the most. The drawback to this test is that only approximate correlation between viability and processability has been established.

RESEARCH IN PROGRESS

It is to be hoped that more complete information on storage and drying conditions and their effect on the processability of grain may be available before long. A number of groups are working toward this end. For example, the Northern Regional Research Laboratory at Peoria, Illinois, is cooperating with the Agricultural Engineering Department of the Illinois Agricultural Experiment Station in a study of the processing of artificially dried corn. The Experiment Station grows, harvests, and dries the corn under known conditions, and the Northern Laboratory makes processing studies on a laboratory scale. Part of the work is nearing completion and should be published shortly.

Federal and state agencies are engaged in studies related to the artificial drying of grain. Current investigations include methods and equipment for artificial drying, the determination of best drying practices, and the effect of different drying and storage procedures on the feeding value of grain.

With so many groups working on the problem, a substantial increase in our information should be attained in the near future.

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